Development of a Measurement Facility for Evaluating Thermal Imagers for Fire Fighter Applications

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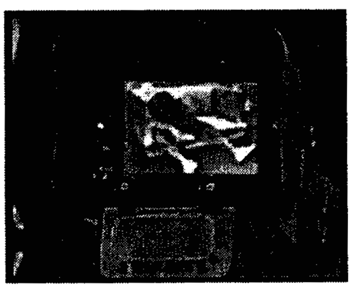
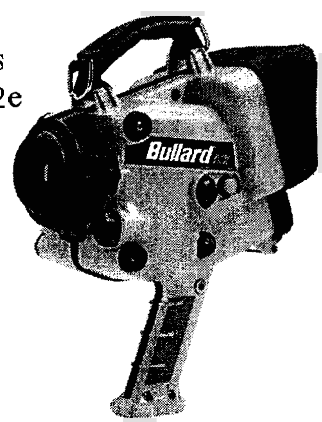
Fire Fighter Thermal Imagers

- Thermal imagers originally developed for military applications
- Current technology has reduced si2e and cost
- Use by fire service is rapidly increasing





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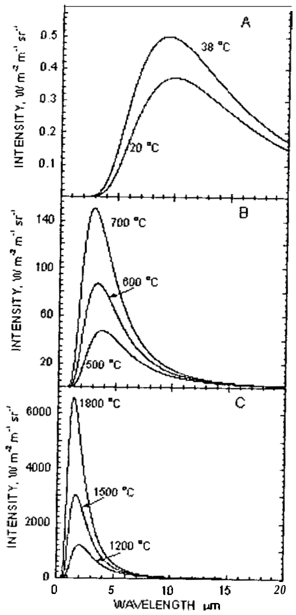

Thermal Emission

Thermal imagers permit fire fighters to "see" by measuring infrared radiation emitted by objects

- All objects emit radiation
- Spectral intensity characteristic of temperature
- Thermal imagers operate in LWIR (8 – 14 μm)

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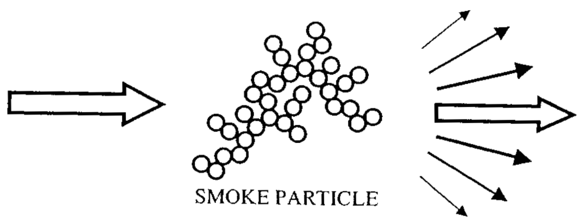
Radiation (Light) Extinction



Rayleigh Theory:

$$\sigma_s = \frac{32\pi^4 a^3}{\rho_s \lambda^4} F(m) + \frac{6\pi}{\rho\lambda} E(m)$$

scattering *absorption*

$$F(m) = \left| \frac{m^2 - 1}{m^2 + 2} \right|^2$$

$$E(m) = \mathrm{Im}\left(\frac{m^2 - 1}{m^2 + 2} \right)$$

Infrared radiation penetrates smoke particles, mist, and sprays more effectively than visible radiation.

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Thermal Imager Applications

- Size Up
- Fire Attack
- Search and Rescue
- Ventilation
- Overhaul
- Training
- Fire Fighter Safety
- Hazardous Materials
- Wildland Fire Fighting

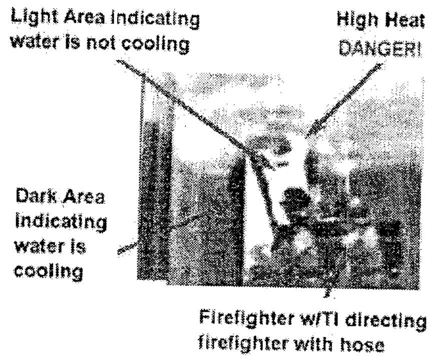
Size up

Heat in attic shows spreading fire conditions

Hottest Spot most likely the seat of the fire

Thermal imagers allow fire fighters **to** find fire sources quickly

Fire Attack



Thermal imagers help incident commanders allocate resources at a fire and quickly get water on the fire.

Search and Rescue

Thermal imagers permit fire fighters to scan rooms in seconds compared to crawling around blindly groping for victims.

Other Application Examples

Overhaul – Fire fighters can scan for hot spots that might re-ignite.

Hazardous Materials – Fire fighters can identify sources and movement of chemicals.

Wildland Fire Fighting – Thermal imagers permit rapid scanning of large areas.

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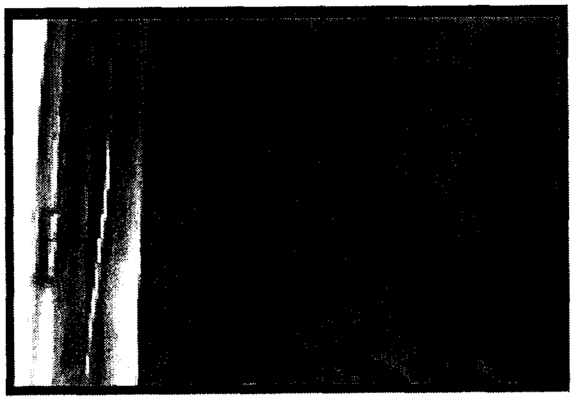
Thermal Imagers in Action



Video demonstrates the advantages **of** using thermal imagers for improved visibility in smoke-filled enclosures.

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Objectives

- Develop a new measurement facility to evaluate the performance of fire fighter thermal imagers
  - Well-controlled parameters
  - Quantitative metrics
- Evaluate the performance of fire fighter thermal imagers under field conditions
- Correlate the laboratory performance with the field performance

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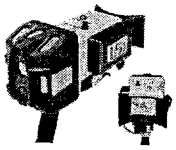
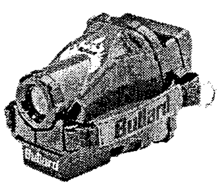
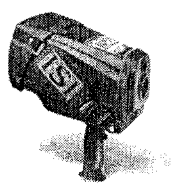
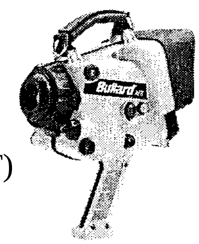
Thermal Imager Detectors







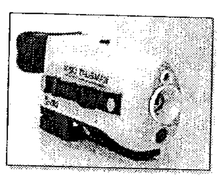
***Infrared** Detectors*



Barium Strontium Titanate (BST)
Solid State Sensor

Vanadium Oxide (VO)
Microbolometer

Amorphous Silicon (AS)
Microbolometer



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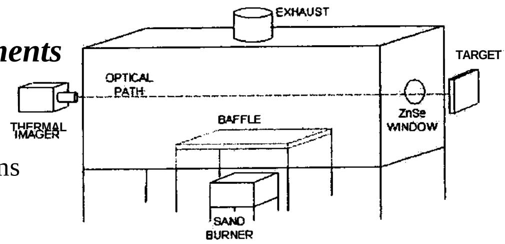
Performance Evaluation

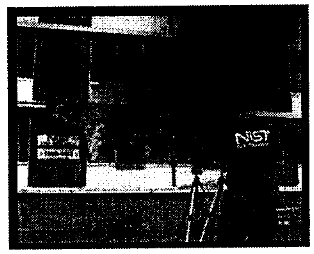
Laboratory-Scale Experiments

Well-defined targets
Controlled media
Reproducible conditions



Full-Scale Experiments

Realistic targets
Indoor vs. outdoor
Realistic conditions (T, f_v, etc.)
Less-controlled conditions



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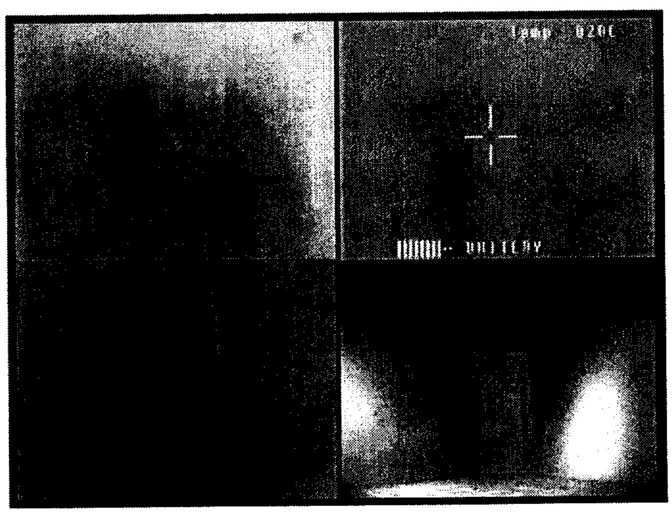
Full-Scale Test

IR

IR



IR

visible

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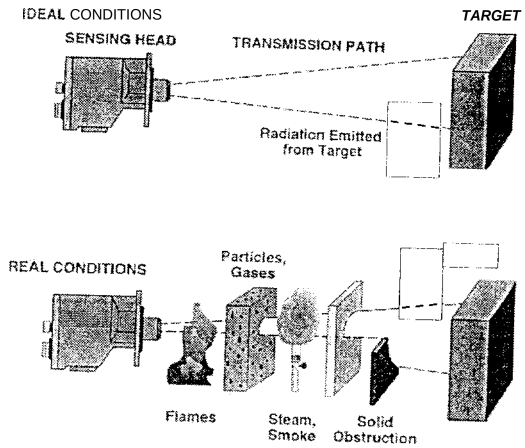
Participating Media

- Hot gases
- Hot smoke
- Water sprays
- Steam
- Other?



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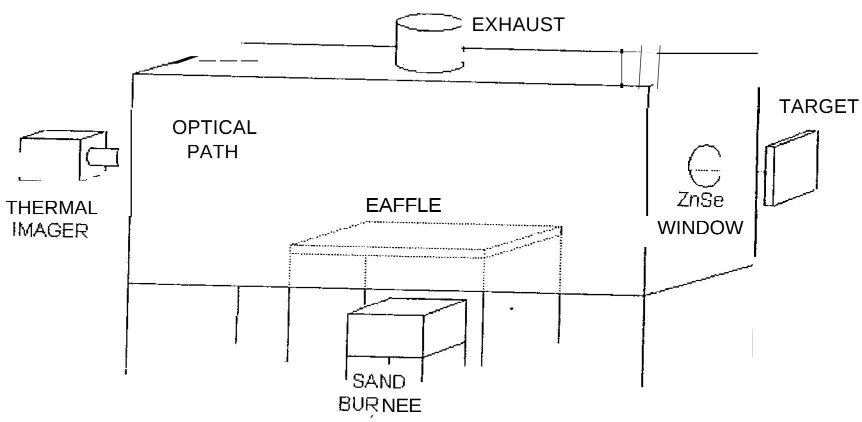
Thermal Imager Evaluation Facility



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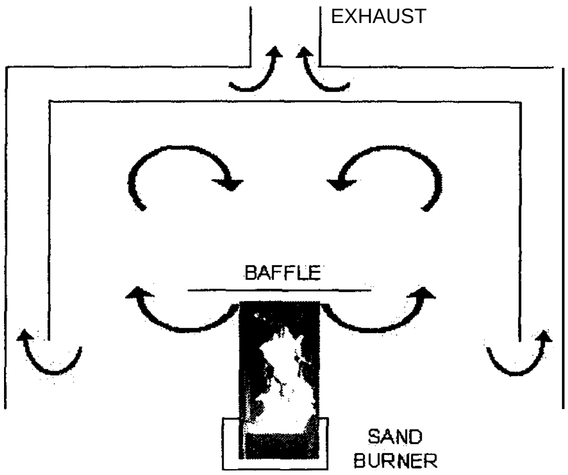
Evaluation Facility (2)



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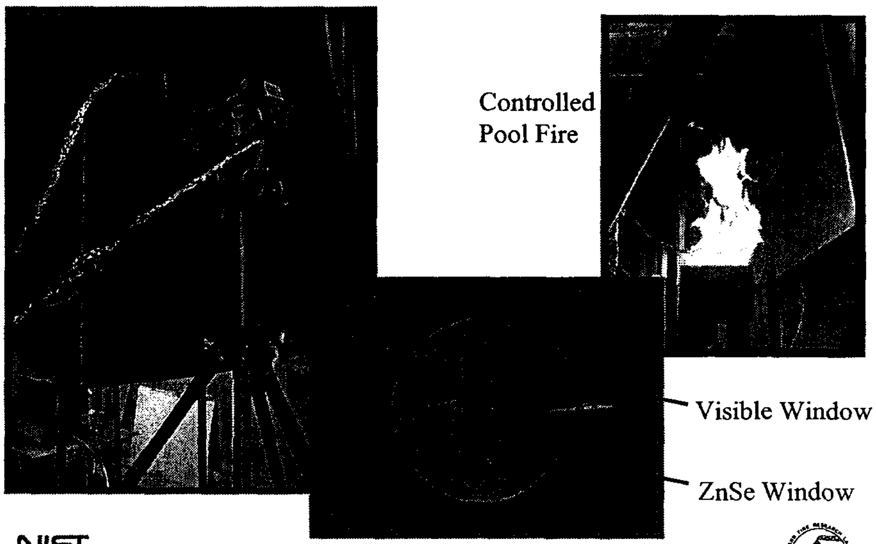
Evaluation Facility (3)



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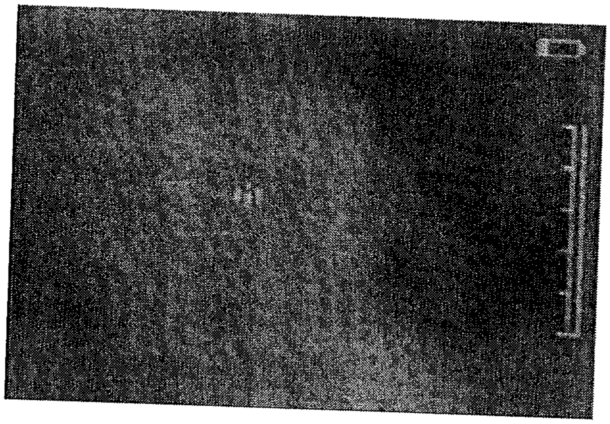
18 kW Propane Fire



Fuel pressure: 5 psig
Flow rate: **0.43** g s^{-1}
Fire size: 18 kW

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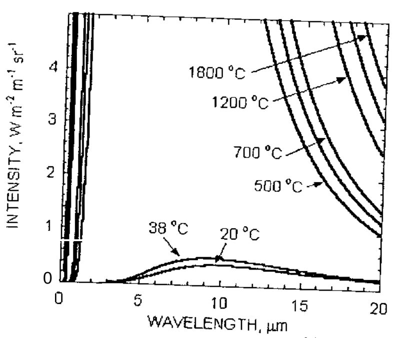
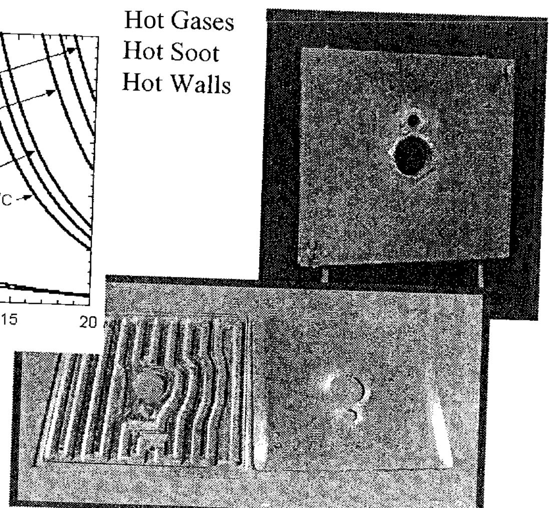
Cooling Plate

Emission from:
Hot Gases
Hot Soot
Hot Walls





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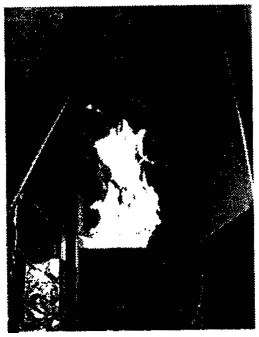
Fire Size



Fuel pressure: 5 psig
Flow rate: 0.43 g s^{-1}
Fire size: 18 kW

Fuel pressure: 10 psig
Flow rate: 0.70 g s^{-1}
Fire size: 30 kW

Fuel pressure: 15 psig
Flow rate: 0.92 g s^{-1}
Fire size: 40 kW

Fuel: Propane

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Particulate Density

Propane flow rate: 0.70 g s^{-1}
Acetylene flow rate: 0.0 g s^{-1}
Fire size: 31 kW

Propane flow rate: 0.70 g s^{-1}
Acetylene flow rate: 0.04 g s^{-1}
Fire size: 31 kW

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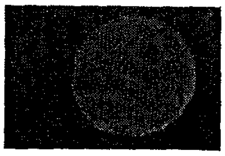
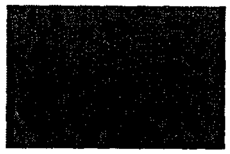
Particulate Density (2)

visible



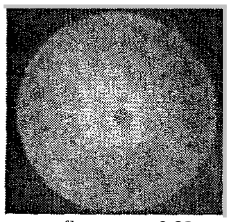
Propane flow rate: 0.70 g s^{-1}
Acetylene flow rate: 0.0 g s^{-1}
Fire size: 31 kW



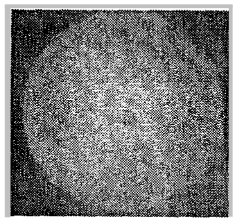
visible

Propane flow rate: 0.70 g s^{-1}
Acetylene flow rate: 0.04 g s^{-1}
Fire size: 31 kW

IR



Propane flow rate: 0.92 g s^{-1}
Acetylene flow rate: 0.0 g s^{-1}
Fire size: 40 kW



IR

Propane flow rate: 0.92 g s^{-1}
Acetylene flow rate: 0.04 g s^{-1}
Fire size: 40 kW

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Quantifying Image Quality

Desirable to have *quantitative metrics* of image quality to evaluate the performance of thermal imagers under different conditions

METRICS

Signal Transfer Function – response to target intensity, varies with the system gain, not a good choice for comparing different systems

Modulation Transfer Function – response to a sinusoidal input, quantifies the ability to discern detail

Contrast Transfer Function – response to a square wave input, similar to MTF but easier to determine experimentally, good choice for thermal imagers

Aperiodic Transfer Function – response to target area, describes systems ability do detect something, may be valuable metric for detecting hot spots.

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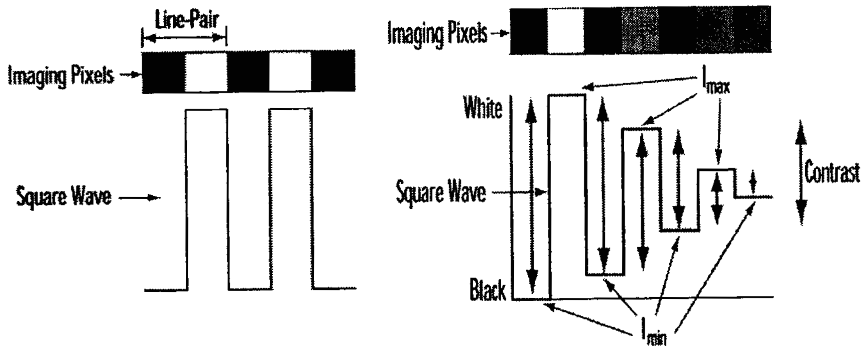
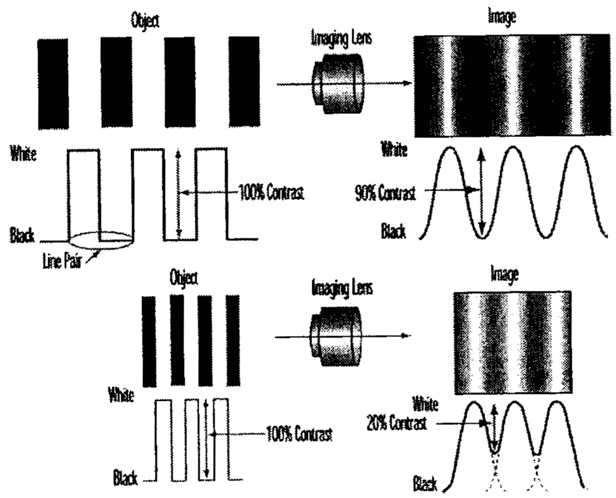
Contrast Transfer Function (CTF)



The CTF measures the system response to spatial frequencies.

Contrast Transfer Function (2)



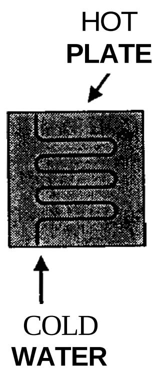
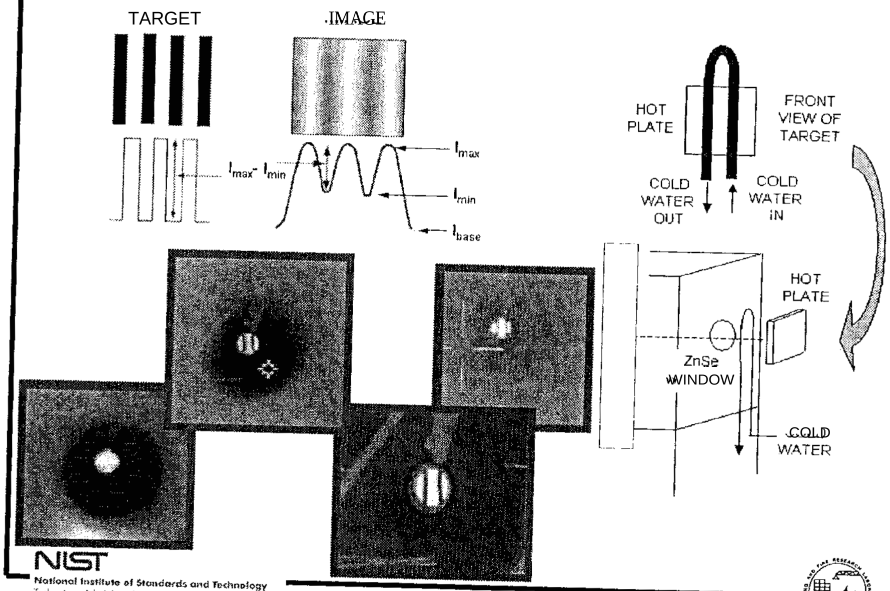


Image of Target



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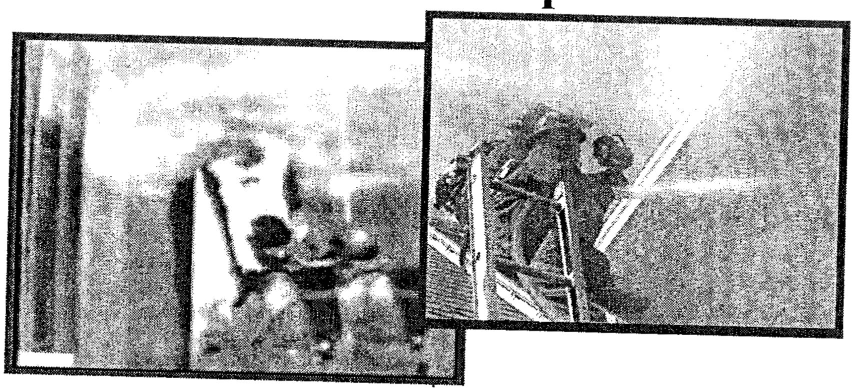
Water Drops



Firefighters may encounter water drops in the form of:

- Sprinkler sprays
- Water mist suppression systems
- Fire hose sprays
- Rain

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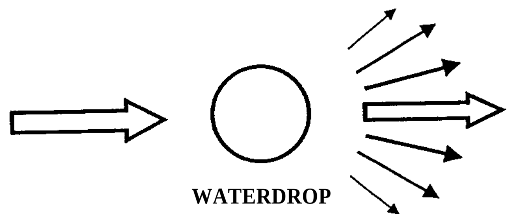
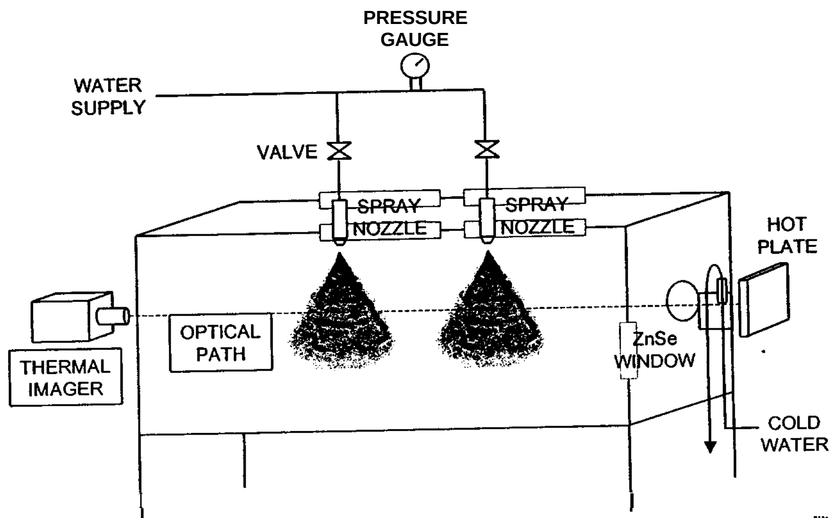
Radiation Extinction by Water Drops



$$\ln[T(\lambda)] = \ln\left(\frac{I(\lambda)}{I_0(\lambda)}\right) = -\int_0^L\int_0^\infty n(D,x)\sigma_{ext}(D,\lambda)\frac{\pi D^2}{4}\,dD\,dx$$

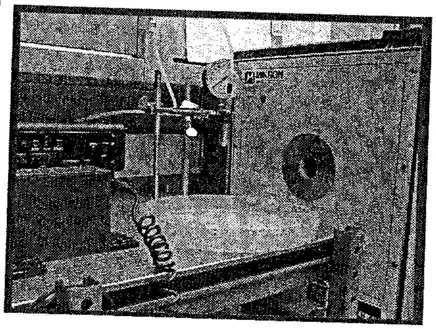
- Optical Extinction Efficiency, σ_{ext}, from Mie theory
- Must integrate over spectral range of detector
- Forward-scatter and in-scatter contribute to noise in image

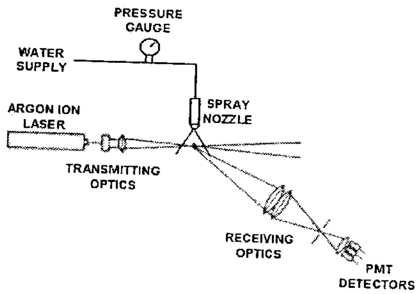
Water Sprays – Laboratory Scale



Water Sprays – Laboratory Scale (2)

$$\ln[T(\lambda)] = \ln\left(\frac{I(\lambda)}{I_0(\lambda)}\right) = -\int_0^L\int_0^\infty n(D,x)\sigma_{ext}(D,\lambda)\frac{\pi D^2}{4}\,dD\,dx$$





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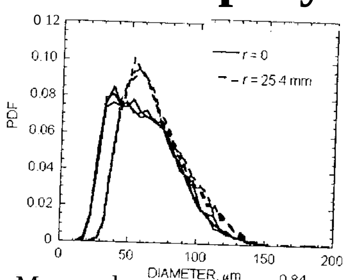
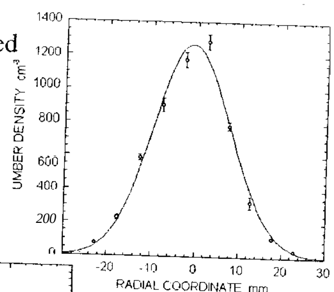
Water Sprays – Laboratory Scale (3)

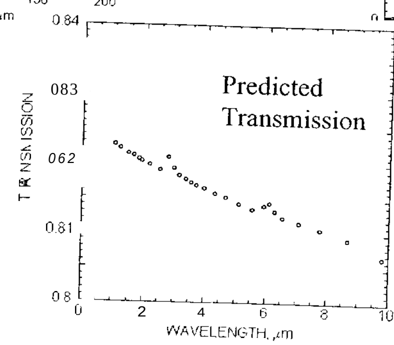


Measured Size Distributions

Measured Number Density Profile



Predicted Transmission



Measured and predicted transmissions showed excellent agreement

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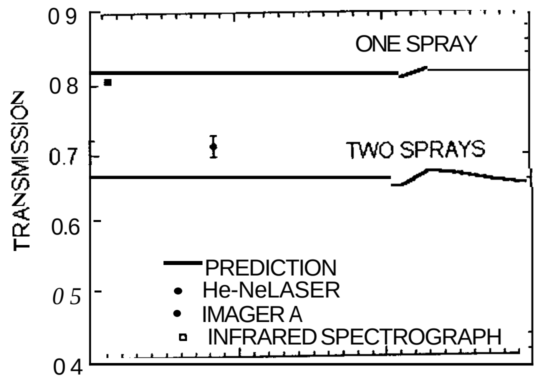
Water Sprays – Laboratory Scale (4)



Additional spray nozzles required to reduce the transmission to the level expected in full-scale applications

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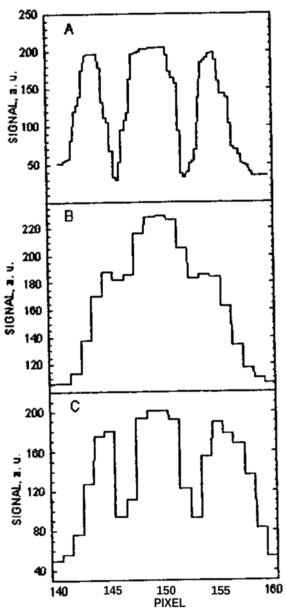
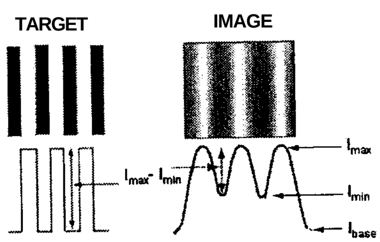
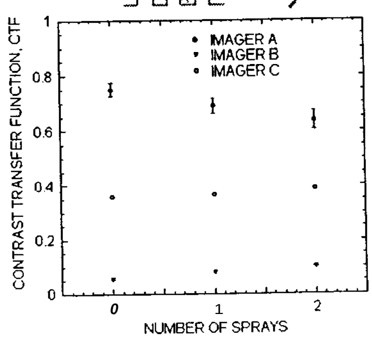
Water Sprays – CTF



$$CTF = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$





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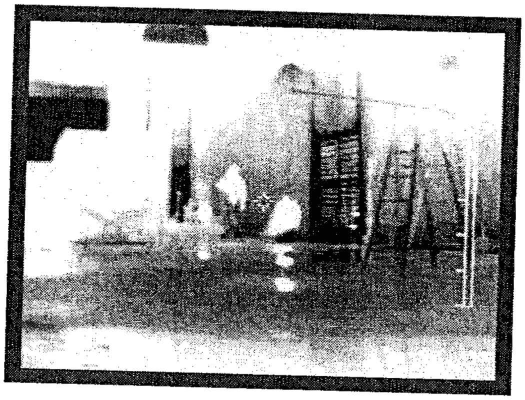
Water Sprays – Full Scale



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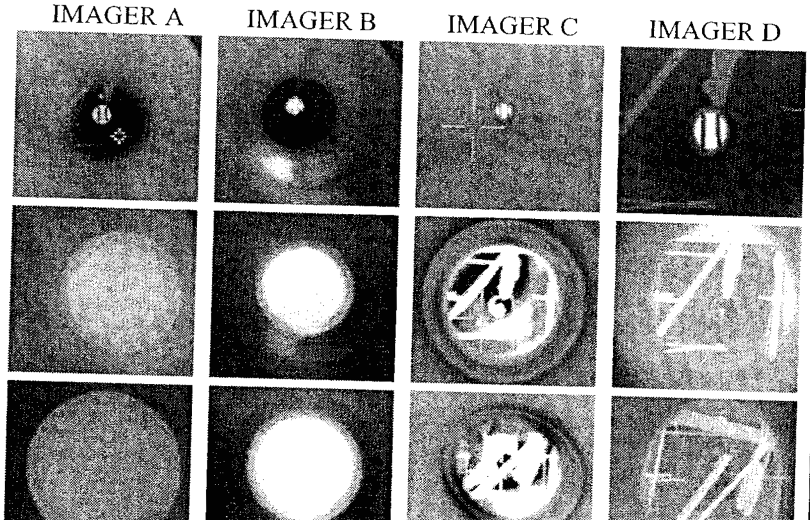
Effect of Gas Temperature

IMAGER A IMAGER B IMAGER C IMAGER D

20 °C

175 °C

375 °C



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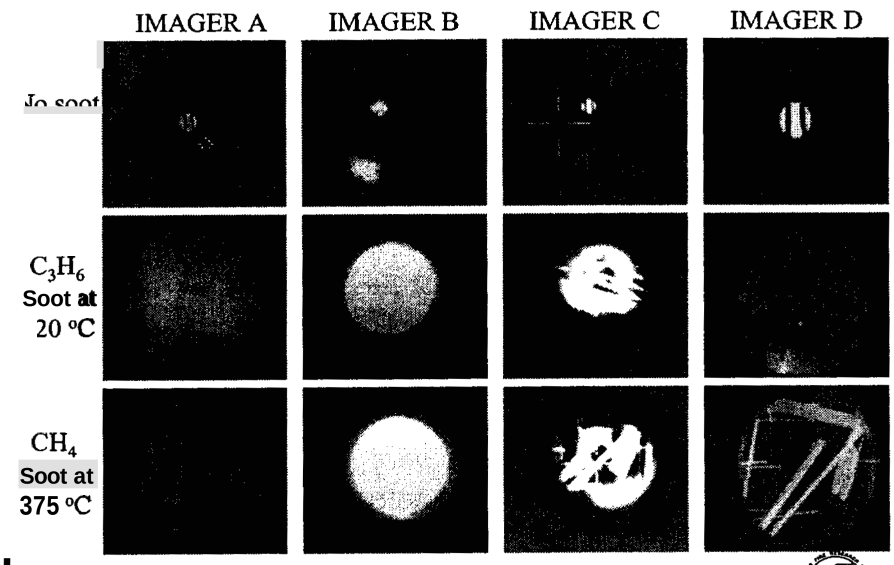
Effect of Particulate



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Summary

Application of fire fighter thermal imagers has shown tremendous increase in recent years, and is projected to increase further in the future.

NIST is working on developing standard tests and protocols for evaluating the performance of these devices for fire fighter applications.

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Future Direction

- Evaluate Quantitative Metrics
- Correlate Lab-scale with Full-scale Tests
- Other Participating Media ?
- Other Performance Attributes ?
  - Refresh Rate
  - Battery Life
  - Submersion Testing
  - Shock Testing
  - Thermal Testing
- Standard Tests/Protocols

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